1.2 A SIMPLE STEP BY STEP METHOD FOR THE ALIGNMENT OF WIND SENSORS TO TRUE NORTH

Robert A. Baxter *
Parsons Engineering Science
Pasadena, California

1. INTRODUCTION

The alignment of wind sensors to a known direction has traditionally presented a challenge to even the most experienced user. The common thread for most alignment methods is to use the reference to true north. Once this reference direction is accurately determined, the alignment of the wind sensor is adjusted either in software programming or with the hardware to read north or 0°. It is the determination of that true north direction that has been the subject of discussions and development of various methodologies.

This paper discusses some of the problems associated with the determination of true north using magnetic methods and traces the history of the presented methodology development. While not intended as a ground breaking technology, the presented method serves to establish a consistent set of procedures that will provide individuals responsible for the setup and verification of wind measurement equipment with a clear, unambiguous and repeatable method for sensor alignment.

2. MAGNETIC DECLINATION METHODS

The United States Geological Survey (USGS) has provided an indication of the deviation of magnetic north from true north on each of their topographic maps. Because of the constant changing of the earth's magnetic field, the magnetic deviation, or declination as it is known, is periodically updated when the maps are revised with the year of the applicable declination provided on each map. This indicated declination has typically been used as the value the magnetic reading obtained in the field needs to be adjusted by to obtain true north. While the declination does change from year to year, the change is relatively small compared to the typical accuracy of most wind measurement systems.

For systems that required more accuracy in the determination of true north, the declination of a given location could be calculated from GEOMAG, a model that was supported by the USGS. For those individuals with modem access during the 1980's the USGS supported a dial up number that would allow users to enter the exact location of a site and the model provided the magnetic declination, along with the rate of change by year. While the calculation of declination was accurate, it still required a measurement that was made using a magnetic compass. This measure is subject to errors due to aberrations in the local magnetic field. These aberrations could be due to soil types (high ferrous content) or ferrous metal debris buried underground. The author has seen local variations in the magnetic field due to buried metal of over 20°. An example of such a location was a site that was over the city of Old Valdez, Alaska. This city was leveled in 1964 by a magnitude 9.2 earthquake and subsequent tidal surge. All that remains are concrete foundations and underground plumbing. Measurements of the wind direction sensor alignment varied by over 20° by simply moving a few meters toward or away from the cross arm of the sensor. The vast array of underground steel significantly affected the surface magnetic measurements.

Even with the correct determination of magnetic declination, and the absence of magnetic aberrations in the local environment, there is still a chance that the magnetic declination may be applied in the incorrect direction. If an individual always performs calculations in roughly the same locale, the correction for magnetic declination will always be in the same direction (i.e., either added or subtracted). However, even the most experienced individuals can be confused in the field when place under the stress of tight time schedules and unfamiliar corrections. Such was the case in 1990 during a major field study encompassing the Central Valley of California. As part of the quality assurance training, one of the initial workshop exercises was designed to ensure all auditors and project personnel used methods that would consistently and accurately find the wind direction sensor alignment that was corrected to true north. The test was simple, find the direction to a selected water tower and express the direction relative to true north. Of the eight or so groups that participated in the workshop, seven had answers that were within ±2° of each other. The remaining group had an answer that was off by approximately 30°. Coincidentally, this happened to be twice the magnetic declination of the particular location where the workshop was held. The measurement group that experienced this error was from the eastern U.S. and was used to applying the declination in the opposite direction. About half of the 30+ sites they were responsible for were already collecting data with incorrectly aligned sensors, but the error was found early in the program and corrected immediately.

3. SOLAR METHODS

To avoid the problems that the application of magnetic declination can introduce, various solar methods have been used. Any of the solar methods require the user know the exact location of the site and have an accurate measure of the true time (and date). The location is either used to calculate solar angles, or

* *Corresponding author address:* Robert A. Baxter, Parsons Engineering Science, Inc. 100 West Walnut Street, Pasadena, CA 91124; e-mail: rabaxter@earthlink.net

determine the time of solar noon, (the time the sun crosses the north/south axis). With the current technology in handheld Global Positioning Systems (GPS), finding the location to an accuracy suitable for the calculation of solar angles is a simple and inexpensive task.

The True Solar Noon (TSN) method uses the time of solar noon and a theodolite to establish the 180° direction (this may be 0° at some latitudes and times of the year). The theodolite base is locked at the true direction the instant the sun is in the cross hair of the theodolite and the time of TSN is reached. This direction then provides a reference to true north by which a sensor may be aligned. An alternative method is to mark the end of a shadow that is cast by a vertical tower or pole at the exact time of solar noon.

To simplify the solar method and remove the restriction of being at the site at the time of TSN, the azimuth angle of the sun can be calculated at the time the alignment is performed. A Basic program developed by Blackadar (1985) entitled *ALMANAC* provided the ability to calculate the azimuth and elevation angles to the sun, moon and other celestial objects knowing the latitude, longitude, year, month, and exact time of day. For the revision to the USEPA quality assurance guidance in 1989, Lockhart extracted the subroutines from the Blackadar program that calculated the sun's azimuth, elevation and solar noon values based on the required inputs. The information from this revised program could then be compared to the magnetic azimuth measurements of the sun to calculate the local magnetic deviation at the point of measurement. A general description of this methodology is provided in the EPA guidance (USEPA, 1995).

In 1990 the Basic program extracted by Lockhart was refined and a simplified front end placed to input the needed variables to calculate a series of 45 solar azimuth and elevation angles at specified time intervals, and provide a more "user friendly" means of inputting the site data. A subsequent rewrite of the program resulted in *COMPASS*, which allows the site variables to be stored and later retrieved. The program *COMPASS* provides the basic input information, along with the site latitude and longitude, which is used in the following step-by-step true north determination methodology. The *COMPASS* program is freeware and can be obtained from the author.

4. STEP-BY-STEP ALIGNMENT DETERMINATION METHODOLOGY

The calculation methodology requires the following equipment:

- Transit or tripod mounted compass that has the ability to be read to at least 1° accuracy. The 1° accuracy will assure an appropriate alignment of the wind sensor that will meet the EPA recommended alignment accuracy of the sensor to be within ±2° (USEPA, 2000).

- Site location in latitude and longitude (a simple handheld GPS is adequate). An accuracy of about one minute is sufficient as long as the readings are not taken at the time of solar noon with high sun elevation angles.

- Accurate time standard, correct to the nearest 5 seconds (the handheld GPS provides such a time standard). At the time of solar noon, with high solar angles, the suns' azimuth angle may change rapidly. For example at an elevation angle of 88° the azimuth angle will change at a rate of about 7° per minute of time. At low solar angles, and times well away from solar noon the time accuracy is not as critical.

- Program such as *COMPASS* to calculate the sun's azimuth direction at the time of measurement. *COMPASS* also displays the elevation angle of the sun and the time of solar noon.

The following is a step-by-step procedure to measure the alignment of a sensor relative to true north.

Step 1 -- Measure the relative pointing direction

Place a compass or transit at a location so that it is looking straight down the cross arm or alignment rod for the wind direction sensor. Note the indicated direction of the transit when it is aimed down the cross arm. It is not important to have the transit or compass independently aligned to a known direction since the measurements being made of the sensor and the sun are relative to each other. What is measured here is the pointing angle of the sensor's alignment cross arm. Call this angle $A_{pointing}$. Figure 1 illustrates a side view of the field setup. Figure 2 shows the measurement using a magnetic pocket transit type device that allows the body to be rotated while the needle continuously points to magnetic north.

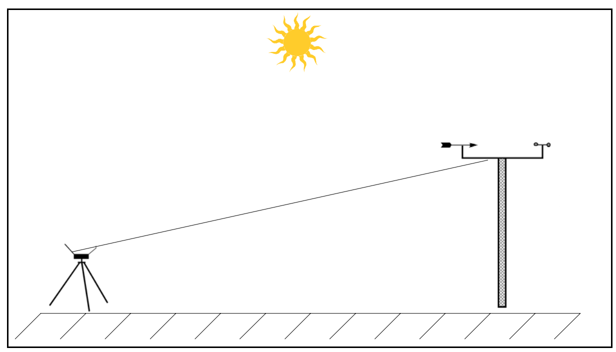

Figure 1. Side view of the placement of a compass or transit for measuring the cross arm direction.

Step 2 -- Measure the sun's relative azimuth angle

Without physically changing the ground location of the transit or compass, rotate the head to obtain a direct measure of the sun's azimuth angle, as shown in Figure 3. Care should be exercised so as to not look directly into the sun. Eye damage may result from looking at the sun without suitable protection. If a "pocket transit" such as one made by Brunton is used, then the mirror can be set to project the sun and the sighting points and lines on a white piece of paper or other flat object. Figure 4 shows how the Brunton transit can be used to perform the projection. When the solar azimuth angle is identified, the exact time of the measurement is noted. This time is used to calculate the actual azimuth angle to the sun. Call the measured angle $S_{uncorrected}$.

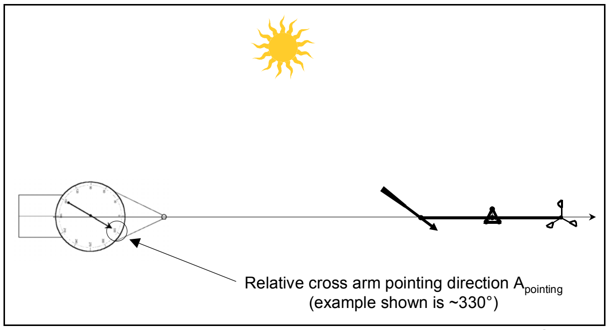

Figure 2. Top view illustrating the measurement of the relative direction of the cross arm.

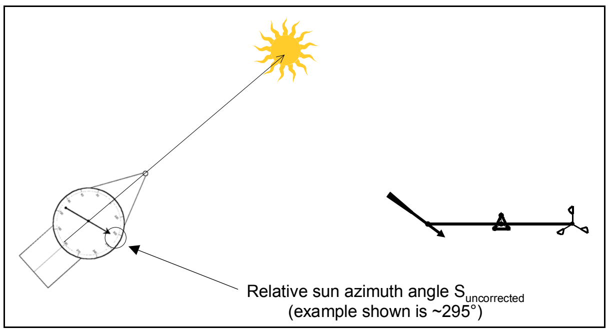

Figure 3. Measurement of the relative direction of the sun.

Figure 4. Projection of sun's reflection using a Brunton Pocket Transit.

Step 3 -- Calculate the sun's actual azimuth angle

Using a suitable program, calculate the true azimuth angle of the sun at the exact date, time and location that the reading of sun's azimuth angle was measured ($S_{uncorrected}$). Call this angle S_{true}. Figure 5 shows a typical display from the program *COMPASS* that uses the latitude, longitude, date, time and specified time intervals to calculate a series of true sun azimuth and elevation angles.

Step 4 -- Calculate the local deviation

Calculate the local deviation by subtracting the uncorrected sun angle ($S_{uncorrected}$) from the true sun angle (S_{true}). Call this difference the local deviation (D_{local}.). This forms the equation:

$$D_{local} = S_{true} - S_{uncorrected} \tag{1}$$

Step 5 – Calculate the cross arm true alignment

Calculate the true pointing direction (A_{true}) of the sensor cross arm or alignment rod using the uncorrected pointing angle ($A_{pointing}$) and the calculated local deviation (D_{local}):

$$A_{true} = A_{pointing} + D_{local} \tag{2}$$

The calculated pointing direction is now referenced to true north based on the known azimuth angle of the sun.

Step 6 – Align the wind direction sensor

Now that the cross arm true direction is known, the wind sensor is physically aimed down the cross arm in the direction of A_{true}, and the housing of the sensor adjusted to make the wind direction value on the data collection system read the value of A_{true}. The sensor housing is locked down and the wind system is now referenced and aligned to true north.

5. AN EVEN SIMPLER ALIGNMENT METHOD

The author has used the above method for determining sensor alignment for about fifteen years with very good results. As with all methodologies, technology evolution presents new opportunities for improving the way we perform tasks. In May 2000 the Department of Defense removed the Selective Availability (SA) encoding on the GPS satellite constellation. SA code effectively reduced the positional accuracy of commercial GPS receivers to about 50 to 100 meters. With the removal of SA, the accuracy of a simple 12-channel autonomous receiver is now in the range of 5 to 10 meters or better. This accuracy now makes the GPS capable of measuring the direction of travel, or bearing, over short distances.

In June 2000 a major audit program in Central California used simple GPS receivers as the primary tool for auditing the alignment of various types of wind measurement instrumentation. This included simple 10-meter tower based systems as well as the alignment of antennas for sodar and radar wind profiling systems. For each of the audits, the alignment of the sensors were verified by marking a point on the ground about 20 to 30 meters from the cross arm (or antenna) that was in line with the cross arm direction. The GPS was held upright and the path from the marker to the ground location of the cross arm was paced off at normal walking speed. The display of the GPS then provided a bearing, or direction of travel, directly related to the cross arm direction. This path was walked several times in directions both toward and away from the tower, or antenna, to assure the directions were 180° from each other and consistent. This method was found to have an accuracy of about ±1°. Thus, the simple solar method could now be replaced with an even simpler "walking" method.

```
                          COMPASS
                        Version 1.2

    Site: Kapolei            Prepared by: Bob Baxter          07-30-2000
Longitude: 158 05.38 West      Time Zone: 10
Latitude :  21 19.54 North                  Time of Solar Noon: 12:38:43

Time   Elev   Azim           Time   Elev   Azim            Time   Elev   Azim
--------------------         --------------------          --------------------
12:00  80.39  106.94         12:15  83.63  117.78          12:30  86.31  145.82
12:01  80.61  107.44         12:16  83.83  118.87          12:31  86.43  149.01
12:02  80.83  107.96         12:17  84.04  120.04          12:32  86.54  152.41
12:03  81.05  108.51         12:18  84.24  121.29          12:33  86.65  156.02
12:04  81.27  109.08         12:19  84.43  122.62          12:34  86.73  159.85
12:05  81.49  109.68         12:20  84.63  124.05          12:35  86.81  163.86
12:06  81.71  110.31         12:21  84.82  125.58          12:36  86.86  168.04
12:07  81.93  110.98         12:22  85.01  127.22          12:37  86.90  172.34
12:08  82.15  111.67         12:23  85.19  128.99          12:38  86.92  176.73
12:09  82.36  112.41         12:24  85.37  130.89          12:39  86.93  181.16
12:10  82.58  113.18         12:25  85.54  132.94          12:40  86.92  185.57
12:11  82.79  114.00         12:26  85.71  135.15          12:41  86.88  189.93
12:12  83.00  114.86         12:27  85.87  137.53          12:42  86.83  194.17
12:13  83.21  115.77         12:28  86.02  140.09          12:43  86.77  198.26
12:14  83.42  116.74         12:29  86.17  142.86          12:44  86.69  202.18
Press (Q)uit   (R)un again   Use keyboard Print screen function for hardcopy
```

Figure 5. Typical screen display from the program *COMPASS*.

6. DISCUSSION

What has been presented in this paper is not ground breaking technology or high level math. The solar method is intended to provide a simple means of aligning wind sensors in a consistent manner, independent of magnetic methods or corrections. The demonstrated accuracy of the method is repeatable to about 1°, well within the accuracy of typical wind sensors.

One of the very basic limitations of the method is the need for sunlight. Thus, on cloudy or foggy days this method is not applicable and one must revert back to traditional compass methods and application of simple magnetic declination, or the above GPS “walk-off” method.

The indicated GPS “walk-off” method was found to be a very simple, easy to implement means of verifying the alignment of sensors. However, this method also has limitations. Some meteorological sites may not have a straight path for walking in the direction of the sensor alignment. Additionally, the Department of Defense reserves the right to enable the SA code or selectively turn off GPS satellites at any time when national security may be threatened. Any of these conditions could severely limit the usefulness of the GPS method.

In summary, the alignment of wind sensors has evolved from a simple compass measurement and application of a magnetic declination, to the use of measured solar angles and Global Positioning System satellite technology. Both the solar method presented here and the GPS method provides an unambiguous means of establishing a sensor alignment relative to true north.

7. REFERENCES

Blackadar, A. F., 1985: Almanac for a weather station. Heldref Publications, Washington, DC 20016

U. S. Environmental Protection Agency, 1995: Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements. EPA-600/R-94/038d, Office of Research and Development, Research Triangle Park, NC.

U. S. Environmental Protection Agency, 2000: Meteorological Monitoring Guidance for Regulatory Modeling Applications. EPA-454/R-99-005, Office of Air Quality Planning and Standards, Research Triangle Park, NC.